CS 153
Design of Operating Systems

Winter 2016

Lecture 5: Processes and Threads

Announcements

- Homework 1 out (to be posted on ilearn)
- Project 1
    - Make sure to go over it so that you can ask the TAs in lab if anything is unclear
    - Both design document and code due before class on Feb. 3rd
- Read scheduling and synchronization in textbook
    - Don’t wait for these topics to be covered in class
    - You especially need to understand priority donation in project
- Piazza enrollment
    - Some of you haven’t enrolled
    - You will miss announcements – especially about projects
- All set with project groups?
    - Email your TA today if you have not notified group or if you are looking for a partner

Process Creation: Unix

- In Unix, processes are created using fork()

  `int fork()`

  `Usually combined with exec()`

  `fork() + exec() ~= CreateProcess()`

- fork()
  - Creates and initializes a new PCB
  - Creates a new address space
  - Initializes the address space with a **copy** of the entire contents of the address space of the parent
  - Initializes the kernel resources to point to the resources used by parent (e.g., open files)
  - Places the PCB on the ready queue
- Fork returns twice
  - Returns the child's PID to the parent, "0" to the child

fork()

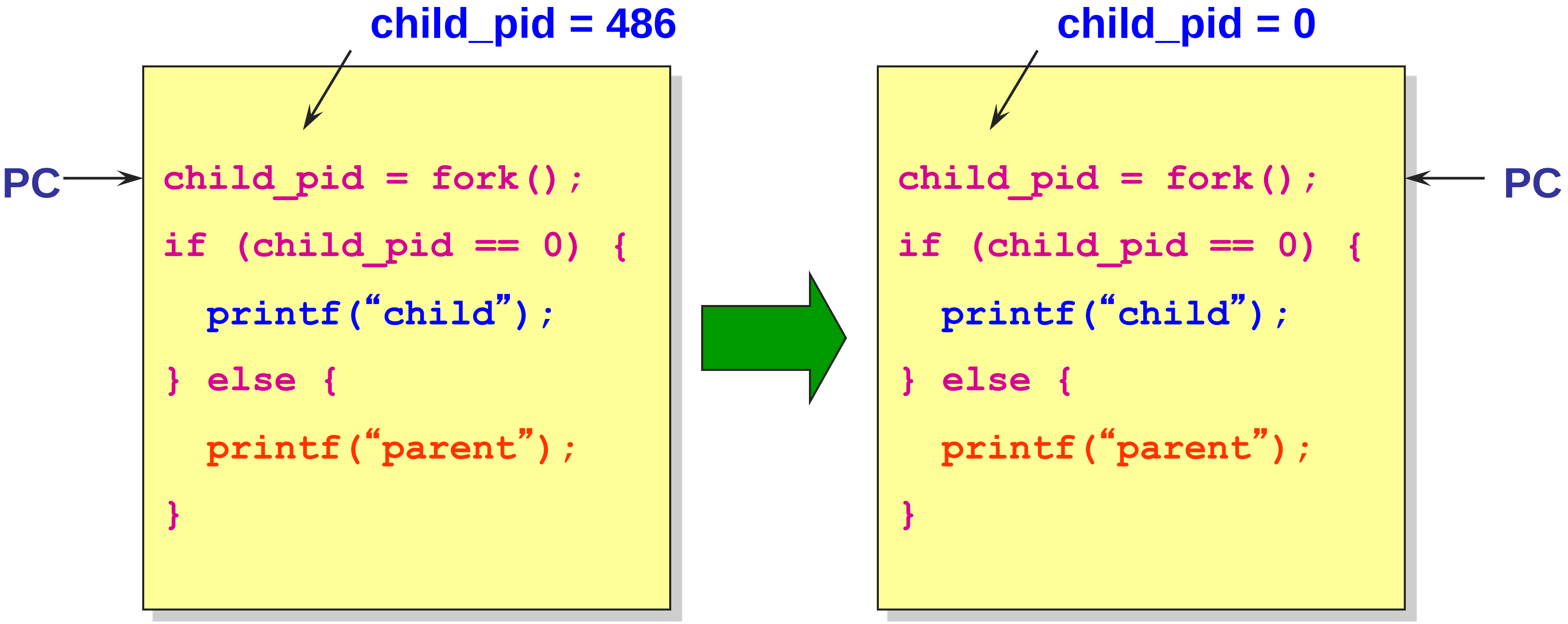
```
int main(int argc, char *argv[])
{
   char *name = argv[0];
   int child_pid = fork();
   if (child_pid == 0) {
        printf(“Child of %s is %d\n”, name, getpid());
        return 0;
   } else {
        printf(“My child is %d\n”, child_pid);
        return 0;
   }
}
```

What does this program print?

Example Output

```
[well ~]$ gcc t.c
[well ~]$ ./a.out
My child is 486
Child of a.out is 486
```

Duplicating Address Spaces



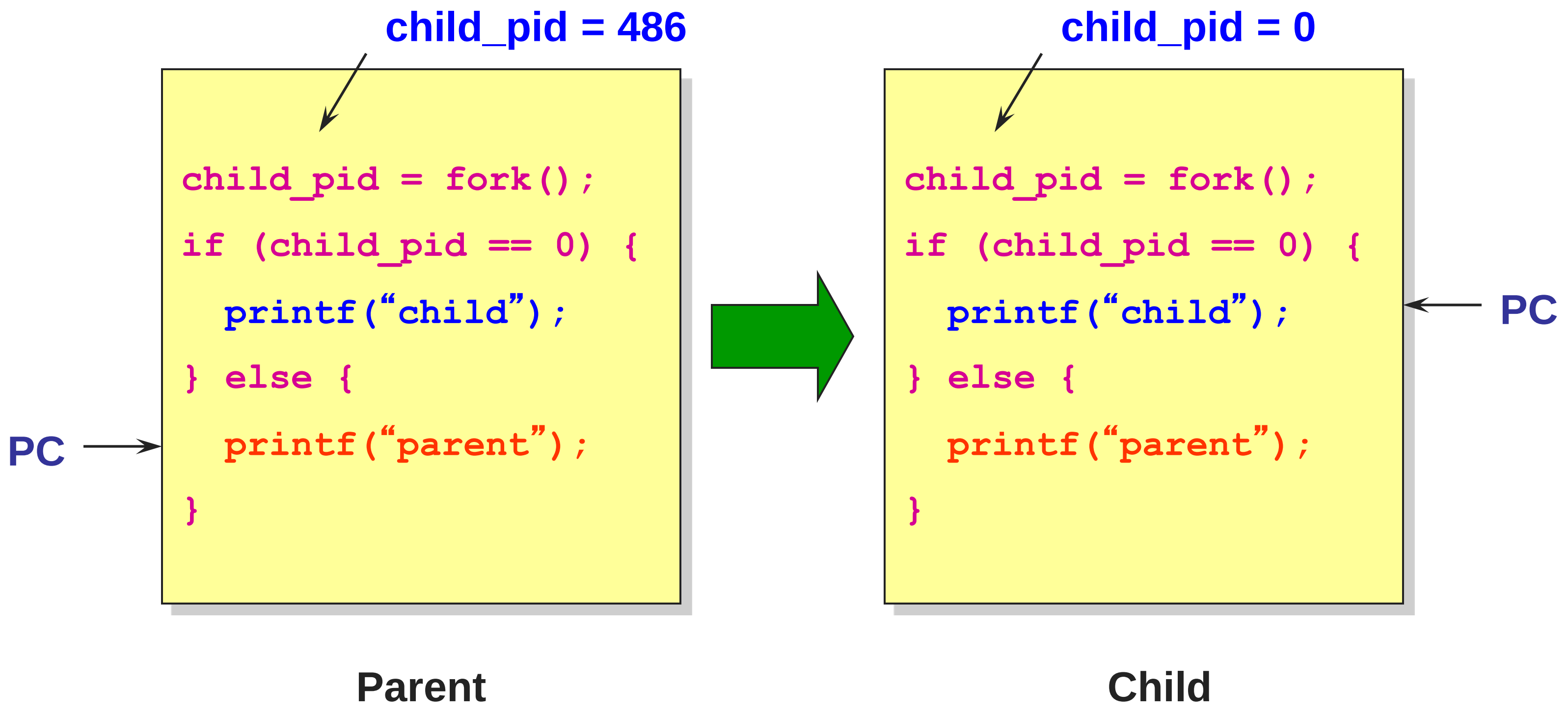
```
child_pid = fork();
if (child_pid == 0) {
  printf(“child”);
} else {
  printf(“parent”);
}
```

Parent

```
child_pid = fork();
if (child_pid == 0) {
  printf(“child”);
} else {
  printf(“parent”);
}
```

Child

Divergence



child_pid = 486

```
child_pid = fork();
if (child_pid == 0) {
  printf("child");
} else {
  printf("parent");
}
```

PC

Parent

child_pid = 0

```
child_pid = fork();
if (child_pid == 0) {
  printf("child");
} else {
  printf("parent");
}
```

PC

Child

Example Continued

```
[well ~]$ gcc t.c
[well ~]$ ./a.out
My child is 486
Child of a.out is 486
[well ~]$ ./a.out
Child of a.out is 498
My child is 498
```

Why is the output in a different order?

Why fork()?

- Very useful when the child…
  - Is cooperating with the parent
  - Relies upon the parent’s data to accomplish its task
- Example: Web server

```
while (1) {
  int sock = accept();
  if ((child_pid = fork()) == 0) {
    Handle client request
  } else {
    Close socket
  }
}
```

Process Creation: Unix (2)

- Wait a second. How do we actually start a new program?

  `int exec(char *prog, char *argv[])`

- exec()
  - Stops the current process
  - Loads the program “prog” into the process’ address space
  - Initializes hardware context and args for the new program
  - Places the PCB onto the ready queue
  - Note: It **does not** create a new process
- What does it mean for exec to return?
- What does it mean for exec to return with an error?

Process Creation: Unix (3)

- fork() is used to create a new process, exec is used to load a program into the address space

- What happens if you run “exec sh” in your shell?
- What happens if you run “exec ls” in your shell? Try it.

- fork() can return an error. Why might this happen?

Process Termination

- All good processes must come to an end. But how?
  - Unix: exit(int status), NT: ExitProcess(int status)
- Essentially, free resources and terminate
  - Terminate all threads (coming up)
  - Close open files, network connections
  - Allocated memory (and VM pages out on disk)
  - Remove PCB from kernel data structures, delete
- Note that a process does not need to clean up itself
  - OS will handle this on its behalf

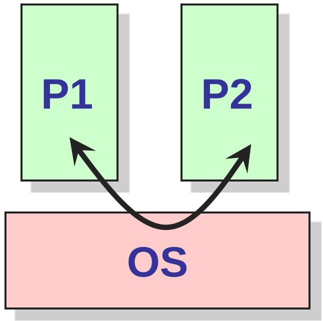
wait() a second…

- Often it is convenient to pause until a child process has finished
  - Think of executing commands in a shell
- Use wait() (WaitForSingleObject)
  - Suspends the current process until a child process ends
  - waitpid() suspends until the specified child process ends
- Wait has a return value…what is it?
- Unix: Every process must be reaped by a parent
  - What happens if a parent process exits before a child?
  - What do you think is a “zombie” process?

Unix Shells

```
while (1) {
   char *cmd = read_command();
   int child_pid = fork();
   if (child_pid == 0) {
        Manipulate STDIN/OUT/ERR file descriptors for pipes,
        redirection, etc.
        exec(cmd);
        panic(“exec failed”);
   } else {
        if (!(run_in_background))
              waitpid(child_pid);
   }
}
```

Processes



- Recall that …
  - A process includes many things:
    - » An address space (all code and data pages)
    - » OS resources (e.g., open files) and accounting info
    - » Execution state (PC, SP, regs, etc.)
  - Processes are completely isolated from each other
- Creating a new process is costly because of all of the data structures that must be allocated and initialized
  - Recall struct proc in Solaris
  - Expensive even with OS tricks
- Communicating between processes is costly because most communication goes through the OS
  - Overhead of system calls and copying data

Parallel Programs

- Also recall our Web server example that forks off copies of itself to handle multiple simultaneous requests
  - Or any parallel program that executes on a multiprocessor
- To execute these programs we need to
  - Create several processes that execute in parallel
  - Cause each to map to the same address space to share data
    - They are all part of the same computation
  - Have the OS schedule these processes in parallel
- This situation is very inefficient
  - Space: PCB, page tables, etc.
  - Time: create data structures, fork and copy addr space, etc.

Rethinking Processes

- What is similar in these cooperating processes?
  - They all share the same code and data (address space)
  - They all share the same privileges
  - They all share the same resources (files, sockets, etc.)
- What don't they share?
  - Each has its own execution state: PC, SP, and registers

- Key idea: Separate resources from execution state
- Exec state also called thread of control, or thread

Recap: Process Components

- A process is named using its process ID (PID)
- A process contains all of the state for a program in execution

Per-Process State

- An address space
- The code for the executing program
- The data for the executing program
- A set of operating system resources
  - Open files, network connections, etc.

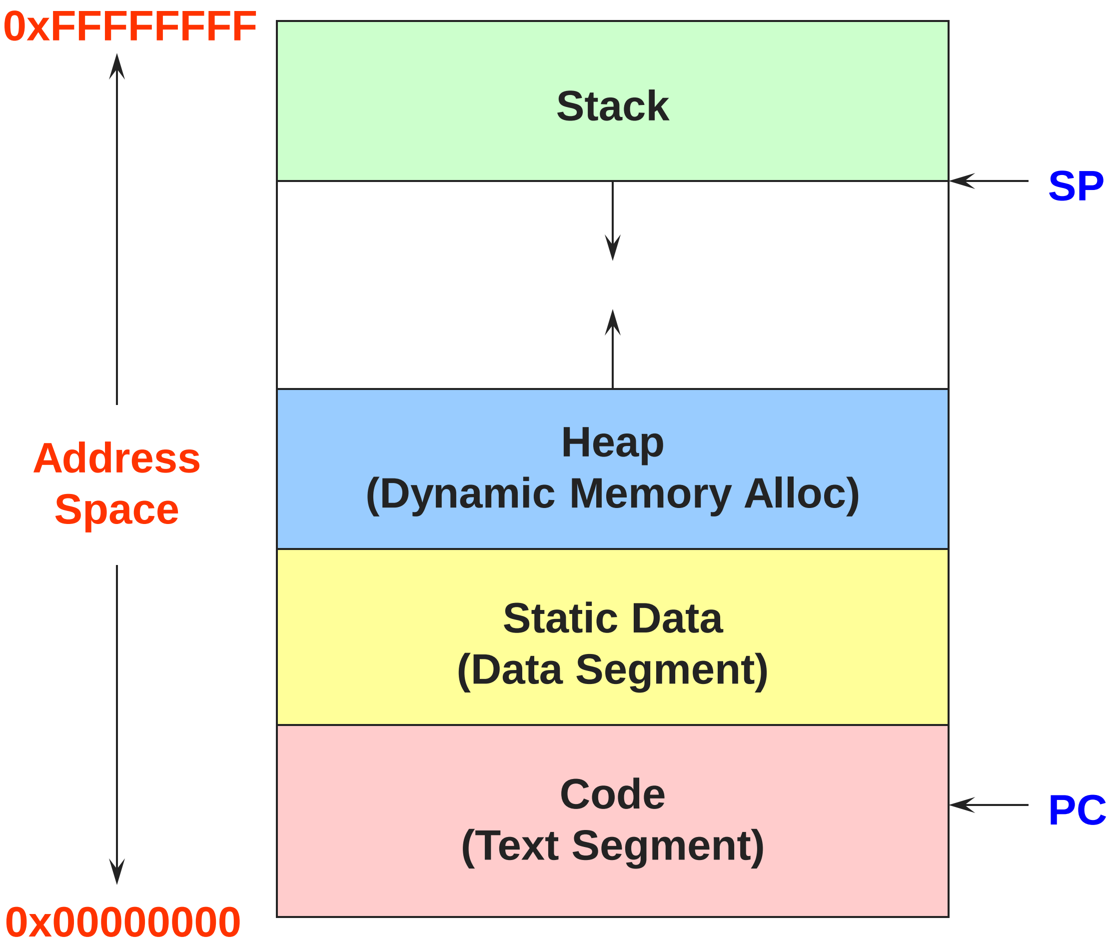
Per-Thread State

- An execution stack encapsulating the state of procedure calls
- The program counter (PC) indicating the next instruction
- A set of general-purpose registers with current values
- Current execution state (Ready/Running/Waiting)

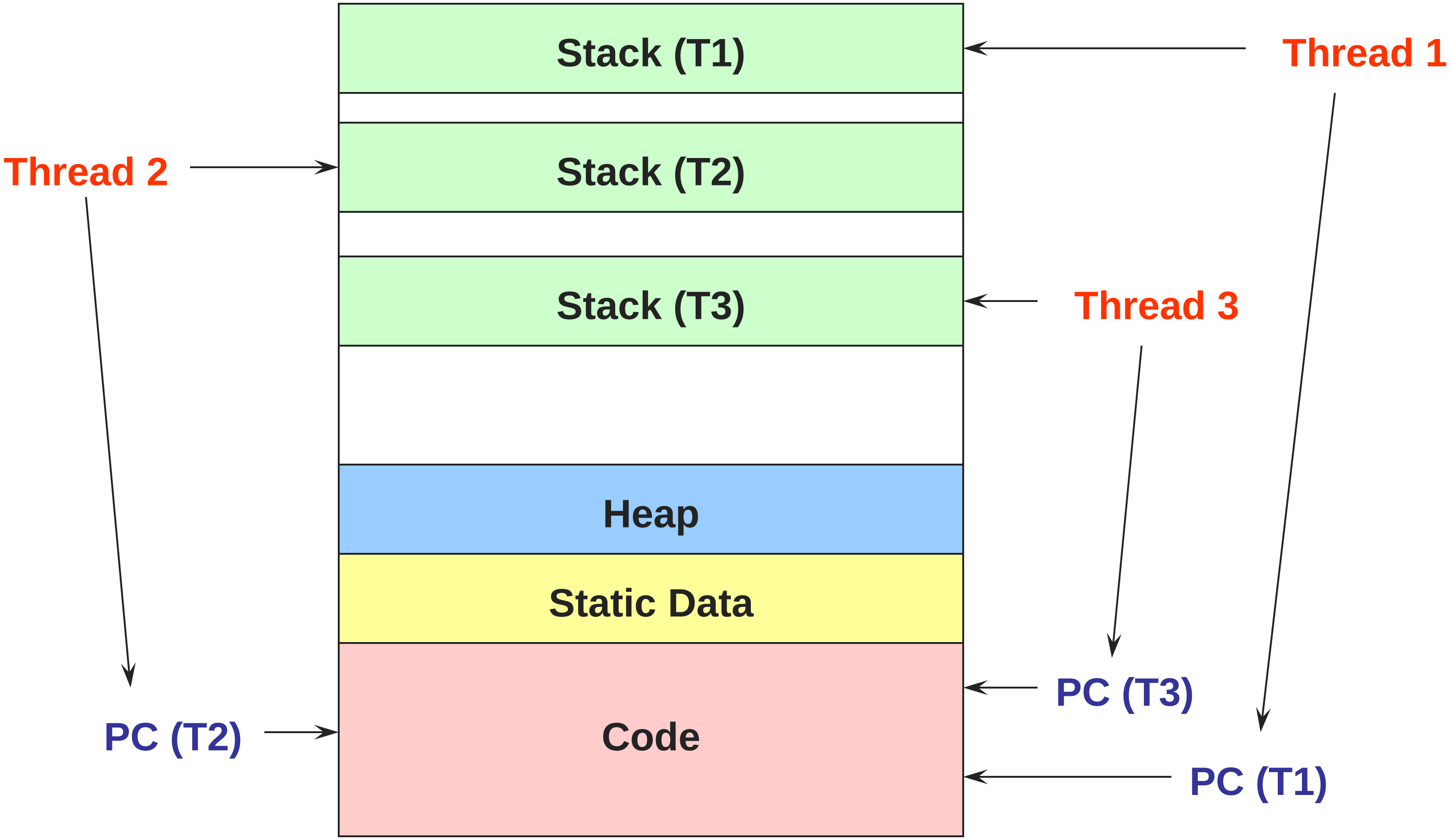
Threads

- Modern OSes (Mac OS, Windows, Linux) separate the concepts of processes and threads
  - The thread defines a sequential execution stream within a process (PC, SP, registers)
  - The process defines the address space and general process attributes (everything but threads of execution)
- A thread is bound to a single process
  - Processes, however, can have multiple threads
- Threads become the unit of scheduling
  - Processes are now the containers in which threads execute
  - Processes become static, threads are the dynamic entities

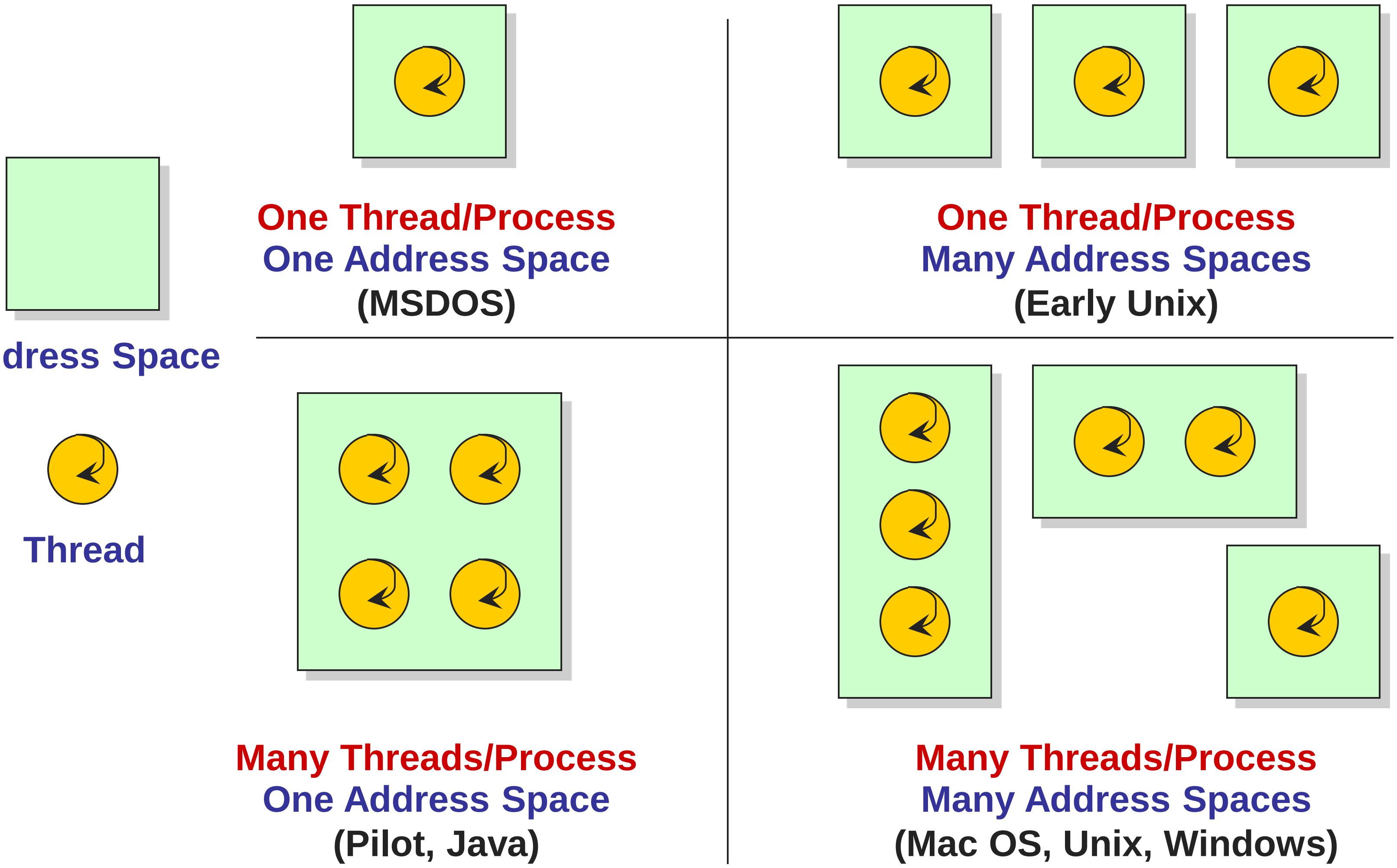
Recap: Process Address Space



Threads in a Process



Thread Design Space



Address Space

Thread

One Thread/Process
One Address Space
(MSDOS)

One Thread/Process
Many Address Spaces
(Early Unix)

Many Threads/Process
One Address Space
(Pilot, Java)

Many Threads/Process
Many Address Spaces
(Mac OS, Unix, Windows)